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Peculiarities of photoluminescence and electroluminescence properties of spontaneously formed periodical InGaAsP/GaAs structures

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Abstract. Double heterostructures with spontaneously formed periodical (SFP) InGaAsP/GaAs active regions have been grown. The dependence of photoluminescence (PL) and electroluminescence (EL) properties of SFP InGaAsP/GaAs structures on excitation level and temperature have been investigated. From analysis of linear polarization rate spectral dependencies of PL SFP InGaAsP/GaAs structures it have been determined that domains with different solid phase composition have lattice mismatch (Δa) value of opposite sign. Threshold current density 50 A/cm² at 77 K have been obtained in laser structures. Strong saturation of longwavelength emission band intensity in room temperature PL and EL spectra with the increase of excitation level have been revealed.

Introduction

In our previous works [1–3] the growth method of spontaneously formed periodical (SFP) InGaAsP/GaAs structures was proposed. This method is based on the use of the spinodal decomposition effect of A³B⁵ multicomponent solid solutions [3–6]. Carried out experimental and theoretical investigations of SFP InGaAsP/GaAs structures showed that such structures consist of domains with different composition periodically interchanged in (001) and (010) directions of the the easiest compression. According to microscopic investigations the dimension of SFP InGaAsP/GaAs domains is 200–600 Å [2]. In present paper investigation of photoluminescence and electroluminescence properties of SFP InGaAsP/GaAs structures have been carried out.

1 Experimental samples

Isotype and anysotype double heterostructures with spontaneously formed periodical (SFP) InGaAsP/GaAs structures as an active region were grown. Active region thickness was 0.2–0.3 μm. Energy bandgaps of SFP InGaAsP/GaAs domains were $E_{g1} = 1.46$ eV and $E_{g2} = 1.72$ eV which correspond to longwavelength and shortwavelength emission bands in luminescence spectra of double heterostructures. Four-cleaved laser diodes were fabricated from anysotype structures. Investigation of luminescence properties of fabricated samples were studied by standard PL and EL technique. For the investigation of linear polarization rate spectral dependencies the original method we had presented in [7–8] was used.

2 Results and discussion

2.1 Photoluminescence properties of spontaneously formed periodical InGaAsP/GaAs structures

Typical photoluminescence spectra of SFP InGaAsP/GaAs structures at room and liquid nitrogen temperatures have longwavelength and shortwavelength emission bands corresponding to radiative recombination in domains with different solid phase composition

(E_{g1} , E_{g2}). The main peculiarity of these spectra consists in temperature dependence of longwavelength and shortwavelength emission band intensities correlation. At liquid nitrogen temperature the correlation of longwavelength and shortwavelength emission bands intensities in PL spectra of SFP structures is well expressed with simple mathematical model taking into account the dependence of thermal distribution and free carriers ejection on potential well depth (E_{g1} , E_{g2}). 77 K PL spectra of SFP structures are similar to PL spectra of InGaAsP/GaAs separate confinement double heterostructures (SC DH) with low-energy active layer (E_{g1}) and high-energy band waveguide (E_{g2}). At room temperature the intensities of longwavelength and shortwavelength emission bands become equal which doesn't correlate with PL spectra of SC DH InGaAsP/GaAs and theoretical model.

PL temperature dependence investigations of SFP InGaAsP/GaAs structures have shown that longwavelength emission band efficiency decreases more rapidly than shortwavelength one with the temperature increase. In SC DH InGaAsP/GaAs structures case the reverse dependence is observed.

The simplest explanation of this phenomenon could be the presence of defects due to non-elastic deformation of SFP structure domains. According to the "soft mode" model, in periodical structure the conjugation of lattice parameters of neighbouring domains is accompanied with an appearance of elastic deformation. However, the calculated value of lattice mismatch of SFP structure domains could reach 3% which results in non-elastic deformation of crystal lattice in the case of bulk epitaxial films [8].

For the determination of deformations in domains of SFP InGaAsP/GaAs structures the formerly designed method of determination of lattice mismatch parameter from spectral dependencies of linear polarization rate was used [8]. In PL spectra of SFP structures the spectral dependence of linear polarization rate has been observed indicating on the presence of elastic deformations. The character of PL spectral dependencies of shortwavelength and longwavelength emission bands indicates on the opposite sign of elastic deformation of domains with different composition. The obtained result confirms the theoretical model [3] and is not in agreement with supposition about the presence of non-elastic deformations in SFP structures.

77 K and 300 K PL spectra of SFP InGaAsP/GaAs structures at different excitation levels have been investigated. Excitation level has been varied from 10 W/cm² to 6 kW/cm². At 77 K the correlation of shortwavelength and longwavelength band intensities has not been changed with excitation level increase. Only longwavelength band broadening and band maximum shift have been observed. The obtained result we connected with some fluctuation of solid phase composition in the domains of SFP InGaAsP/GaAs structures. At room temperature the strong saturation of PL longwavelength band intensity with excitation level increase has been observed. To our opinion it is connected with low volume of domains responsible for longwavelength emission band in comparison with the volume of domains corresponding to shortwavelength emission band.

2.2 Electroluminescence properties of spontaneously formed InGaAsP/GaAs structures

In electroluminescence (EL) spectra of SC DH SFP InGaAsP/GaAs structures shortwavelength and longwavelength emission bands have been also observed. Analogous to 77 K PL spectra in 77 K EL spectra shortwavelength and longwavelength emission bands have been observed. With an increase of pump current up to 50–80 A/cm² the threshold current has been reached. The correlation between lasing wavelength and threshold current has been observed. The minimum value of threshold current has been measured in the samples with maximum lasing wavelength resulting from gain saturation. The strong dependence of lasing wavelength on injection carrier concentration indicate on relatively low volume

fraction of domains with low energy solid solution composition in the whole volume of active region. At room temperature the longwavelength emission band in EL spectra has been observed only at low pump currents. With an increase of pump current longwavelength band intensity saturates and shortwavelength band intensity increases. Room temperature threshold current in four-cleaved diodes was 0.9–1.3 kA/cm² which is in accordance with theoretical and experimental values of threshold current densities for double heterostructure with 0.3 μ m active layer thickness.

Conclusion

Investigation of linear polarization rate spectral dependencies of SFP InGaAsP/GaAs structures revealed the presence of elastic deformations with opposite sign in interchanged domains with different solid phase composition. Threshold current density 50 A/cm² was achieved in double heterostructures with SFP InGaAsP/GaAs active region. The observed strong saturation of longwavelength emission band intensity in temperature dependencies of PL and EL spectra is connected with relatively low volume of domains of low-energy material in SFP InGaAsP/GaAs structures. Simple theoretical evaluations showed that 4–5 times increase of low-energy material volume in SFP structure will allow to reduce threshold current density to 15–20 A/cm² at 77 K and to receive room temperature laser generation at 60–90 A/cm².

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